Private Investment in Livestock Breeding with Implications for Public Research Policy

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ABSTRACT

The private sector is playing an increasingly important role in livestock genetic improvement. Specialized breeding firms now supply virtually all commercial poultry breeding stock and growing market shares of improved genetic material for swine, beef, and dairy cattle. This article examines how incentives for private investment in livestock breeding are affected by consumer demand, market structure, intellectual property protection, new technologies, and market globalization. Survey results collected by the authors provide new evidence on the extent of private spending on livestock breeding. Implications of the findings for public and private roles in research on animal genetic improvement are discussed. © 2000 John Wiley & Sons, Inc.

1. INTRODUCTION

Farm animal production in the United States experienced remarkable productivity growth from the end of World War II to the present. New technologies transformed the way livestock products are produced and processed, and helped deliver a wider variety of higher quality products to consumers. One of the most important factors enabling these changes has been private and public investments in livestock genetic improvement. Over time, the role of the private sector in livestock breeding has grown.

This article examines the incentives for private investment in livestock breeding and presents new survey evidence documenting the extent of these investments in the U.S. and worldwide. Profit incentives for conducting breeding research are uneven across livestock commodities, however, and our descriptive model predicts more intensive private investment in poultry breeding relative to swine, and more in swine breeding relative to beef and dairy cattle. Our survey evidence bears out this prediction. These findings carry important implications for public policy for research and university education for livestock development.

In the next section of the article, we describe factors that affect the profitability of private investments in livestock breeding research and compare these incentives across major livestock commodities. Our principal hypothesis is that private research investments will

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differ among commodities, due to differences in the size of the market, in reproductive technology, and in the ability to appropriate economic benefits from research. In the second section, we test this hypothesis with survey evidence collected by the authors from major firms that conduct breeding research for poultry, swine, beef, and dairy cattle. In the third section, public and private allocation of resources to livestock genetic improvement in the United States are compared. Implications for public research and education policy are discussed. The final section of the article contains a summary of major findings and conclusions.

2. FACTORS AFFECTING PRIVATE-SECTOR INVESTMENT IN LIVESTOCK BREEDING

Pray and Fuglie (1999) identify three key determinants of agricultural research investments by profit-seeking firms: (1) the size of the potential market for new technology; (2) the ease of developing improved technology for a given level of research investment; and (3) the ability of a firm to capture the returns to research investments and protect intellectual property, or “appropriability.” Appropriability addresses the extent of positive externalities from research, i.e., the benefits from research that spill-over to non-payers of the research investment. To this list we would add (4) regulations and trade restrictions that affect incentives for private research investment. Regulations affect the cost of conducting research, bringing a new product to market, and producing the final product. Trade restrictions affect the potential size of the market and the cost of transfering technology across national borders. One of the principal rationales for regulations and trade restrictions is to reduce the potential for negative externalities from livestock production and new technology. Government interventions to increase appropriability, such as through patent law, and reduce environmental and food safety risks, though regulations on product development, production, and trade, both serve to get the private benefits/costs of research more in line with the social benefits/costs. The following discussion examines how each of these factors may influence the profitability of private investment in livestock breeding.

2.1. Demand for Animal Products

The demand for new livestock technology by farmers is derived from consumer demand for the final products. In the United States and several other industrialized countries, demand for improved livestock technology has been affected by at least two major long-term trends. First, there have been major changes in the pattern of consumer demand for animal products. In the United States, per capita consumption of poultry meat has grown significantly over the past three decades, per capita consumption of pork has remained fairly stable, while per capita consumption of beef, eggs, and lamb has declined. These changes in market demand are partly the result of past technical change, which affected the relative prices of close substitutes in food consumption, product innovations, and changes in consumer preferences. For example, more rapid technical change in poultry production helped reduce retail prices of poultry relative to beef. This facilitated the substitution of chicken for beef in consumer diets (Brester, Schroeder, & Minter, 1997). The poultry and pork industries have also developed myriad new food products, including convenience food items, to bolster demand (Brester et al., 1997; Thurman, 1987). Health concerns may have also contributed to shifts in consumption patterns. Consumers increasingly choose leaner meats, for instance. And increased awareness of the link between cholesterol consumption and heart disease may have contributed to the decline in egg consumption (Henneberry & Charlet, 1992).

Table 1. Private-Sector Poultry Breeding Research Programs and Franchises of the Ten Poultry Breeding Companies Surveyed

	Africa & Middle East	Asia & Australia	Latin America	North America & Europe	World
Private poultry breeding research programs	1	4	1	8	14
Location of private companies franchises	30	66	26	49	171

Source: Authors' survey.

The second major demand factor is to the globalization of the market for improved livestock genetics. Improved access to international markets and the growth of world trade has enabled livestock breeding firms to sell their products worldwide. The increase in the size of the potential market strengthens incentives to invest in research to develop new animal production inputs. For example, several of the major poultry and pig breeding firms are multinational companies with breeding and testing stations located in several countries. Table 1 illustrates the globalization of research in the poultry industry, which was obtained from a survey conducted by the authors in 1998 of the major poultry breeders involved in research. In this survey poultry companies were first asked in what countries they conduct research and what percentage of their total research budget corresponded to what countries. Multiple research programs by a specific company in different regions of a country (including the U.S.) were not considered as separate breeding programs. Second, companies were asked in what countries they had franchises and what year these franchises were established. Franchises were defined as whether a company had a breeding outlet in which it sold stock in a specific country. As can be seen from the Table, most private-sector poultry breeding research takes place in North America and Europe, but franchises selling improved genetic material are located worldwide. Through the transfer of technology among these franchises, producers in one country can readily obtain benefits of technology developed in another country.

An expanding market for a commodity encourages greater investments in research on that commodity, because a larger market increases the returns to research. Current investment in research reflects not only current market size but also expected future growth of that market. Rapid growth in U.S. and global poultry meat production in particular has been one of the most important factor explaining the expansion in recent years in private investment in poultry research. This trend can be self-reinforcing, because increased poultry research can encourage further growth in consumption by reducing production costs and market prices of poultry meat products.

2.2. Technological Opportunities

Wide differences in fecundity rates and gestations periods among livestock commodities significantly affect the potential gains in productivity that can be achieved for a given amount of research investment. It takes only five months from the time a chicken egg is fertilized until the hatched chick becomes mature enough to breed. Moreover, chicks retained for breeding are only a small proportion of the production flock since one layer can produce 300 offspring per year. Pigs require less than 12 months from the time a sow is bred and farrowed for the offspring to reach breeding age. Fecundity in swine has been increasing, and most sows are now capable of producing two litters per year of about nine pigs per litter. With cattle, the production cycle is considerable longer. Each cow can produce only one offspring per year and it takes two years from the time a cow is bred for her calf to reach breeding age. Because fecundity and gestation determine the payback period for research investments in breeding, private companies are likely to invest relatively more in poultry breeding relative to swine breeding, and more in swine breeding relative to cattle breeding, other things being equal.

Major advances have occurred in the past decade to improve reproductive technology. Advances in artificial insemination, embryo transfer, and cloning increase the incentives for private research in animal breeding. These technologies can significantly expand the market for a successful breeder of improved parent stock. They speed up the process of genetic improvement, reduce the risk of disease transmission, and expand the number of animals that can be bred from a superior parent. For example, a boar can fertilize up to 2,000 sows per year through artificial insemination but only 100–130 through natural mating (Estienne, 1993).

Another factor that affects technology opportunity is the availability and cost of research resources to the private sector. Public investments in livestock sciences and university education and training of livestock scientists and technicians increase the supply of technological opportunities and research resources and thereby reduce private costs of conducting research.

2.3. Regulations and Trade Restrictions

Regulations governing international trade in live animals, consumer safety tests of new food products, biotechnology, and the humane treatment of animals may either increase or decrease research and commercialization costs. For example, while extensive product testing requirements add to product development costs, they may also reduce potential liability costs by preventing unsafe products from entering the market place. Restrictions on trade in live animals or animal products are often justified on the grounds of preventing disease transmission that may gravely affect a country's livestock sector. This can limit the potential global market for new technology and add considerably to the cost of technology transfer. However, by reducing the risk of a disease outbreak and resulting loss of production, these regulations also help protect the market for new livestock technology within a country.

2.4. Appropriating Economic Benefits of New Technology

Regardless of the size of the potential demand for a new technology, the ability of the private company to sustain profitable sales of the technology is another important incentive for private research. The profitability of research can be undermined if other firms are able to copy a new technology and sell it to producers, or if farmers can reproduce the technology themselves. Copiers can afford to sell the technology more cheaply than the original inventor because they do not have to recoup the initial sunk costs of research and development.

There are several means by which firms may be able to prevent such technology spillovers so that they can appropriate a larger share of the economic benefits from their research. Protection can be in the form of special legal rights, such as patents and trademarks, which prohibit the use of the technology or the brand without permission of the patent or trademark owner. Intellectual property can also be protected through trade secrets. In this case, the company does not make the means of producing or manufacturing the technology public, and the company remains the sole provider of the technology to the market. Market structure also influences appropriability, especially when one or a few large firms dominate an industry and can exercise some monopoly power in the pricing of their products.

2.4.1. Patents and trademarks. Patenting awards an inventor the sole right to use a technology for a specific period of time (usually 20 years) in exchange for publicly disclosing the nature and details of the invention. Patenting is widely used to protect mechanical inventions, especially those which may be easy to copy through “reverse engineering.” Other technologies may be difficult or impossible to patent. Killed viruses used to produce animal vaccines, for example, are generally not patentable because they are considered products of nature. Patent protection for new animal breeds has been available since 1987, but so far no patented animal breed has been sold commercially (Lesser, 1993). Instead, breeders have tended to rely on trade secrets or brand name reputation (trademarks) to protect their technology products from imitators.

2.4.2. Trade secrets. Firms may try to protect intellectual property by keeping key research findings out of the public domain. For example, a firm may keep secret the processes or formulas used in the manufacture of new technology. In the manufacture of animal vaccines using killed viruses, firms often protect intellectual property by keeping secret the processes used to rapidly multiply a virus, formulate the vaccine, and test for efficacy (C. Pray, personal communication, 1998).

Poultry breeders developed a highly successful way of protecting their intellectual property investment in superior breeds by exploiting heterosis, or hybrid vigor (Bugos, 1992). Hybrid vigor is the yield advantage obtained when two or more pure inbred lines are crossed in a breeding scheme. While the offspring of this cross exhibits some superior yield performance, this yield advantage steadily declines as the offspring themselves are bred. Thus, by restricting access to the pure parent line stock (a form of trade secret) a breeder remains the sole supplier of the hybrid. Farmers need to repeatedly purchase new stock from the breeder to maintain high yields.

For most livestock, the production of hybrid animals is not really possible in the sense of hybrid plants or even hybrid poultry. Maximum hybrid vigor is obtained when parent lines are closely inbred. However, close inbreeding is seldom practical in large mammals because reproductive fertility and health of inbred offspring quickly deteriorate. Cattle, for example, have very little excess reproductive capacity because a normal birth is a single calf and a small deterioration results in infertility of the inbred line. Thus in cattle, commercial breeding is normally restricted to unrelated animals using a system of *outcrossing* or *crossbreeding*. Greater fecundity in swine means that greater reproductive capacity exists to exploit heterosis, but the health and vigor of inbred piglets are fragile.

2.4.3. Market structure. Schumpeter (1950) hypothesized that technological change would be greater in industries in which firms could exercise some monopoly power because this would provide them greater incentive to invest in research and development. By exercising monopoly power to raise the price of its products, a firm can thereby recoup the costs of product innovation. In an empirical test of Schumpeter’s hypothesis, Scherer (1980) found that some monopoly power did appear to encourage private investment in research, but that too much monopoly power in an industry reduced the incentive to innovate.

In the U.S. and other countries, the livestock breeding industry, as well as livestock production, have undergone significant structural change in the past few decades. Specialized

Table 2. Companies With Livestock Breeding Programs in the United States, 1996

Broilers	Arbor Acres (Booker plc, UK)
	Avian Farms (Charoen Pokphand, Thailand)
	Cobb-Vantress (Tyson Foods, US)
	Hubbard ISA (includes Hubbard, ISA, and Shaver; Merial, UK)
	Perdue (Perdue, US)
	Peterson Farmers (Crystal Lake, US)
	Ross Breeders (Hillesdown Holdings, UK)
Layers	DeKalb (Toshoku, Japan)
	Hubbard ISA (includes Hubbard, ISA, Shaver and Babcock; Merial, UK)
	Hy-Line International (Lohmann-Wesjohann, Germany)
Swine	Babcock Swine (US)
	Cotswold USA (Heartland Pork Enterprises, UK)
	DeKalb Swine Breeders (Monsanto, US)
	DanBred (Denmark)
	Farmers Hybrid (US)
	Genetic Improvement Service (US)
	Genetic Porc (Canada)
	Nesham Hybrids (US)
	PIC-USA (London-Dalgery PLC, UK)
	Seghers Hybrid (Belgium)
Beef and dairy (suppliers of artificial insemination)	ABS Global (US)
	Accelerated Genetics (US)
	Alta Genetics (US)
	Cooperative Resources International-CRI (US)
	Select Sires (US)
	Sire Power (US)

Company name is followed (in parentheses) by parent company if different from breeder company and country of incorporation.
Source: various industry sources.

companies have emerged to develop high-yielding breeds of broilers, layers, pigs, dairy, and beef cattle. In some cases these companies appear to exercise significant monopoly or oligopoly power over the provision of new breeds to producers. In addition, the growth of integrated poultry, swine, and beef cattle production systems, in which breeder firms are joined in the same corporate structure with production farms, feed companies, processing plants, and even retail stores, have further enhanced private incentives to invest in breeding research. In integrated systems, the corporate owner is able to capture the gains from research by applying the technology within the firm rather than through product sales to other companies. Internal "sales" are sufficiently large to justify the investment of research.

Table 2 lists the companies with significant investments in animal breeding for layers, broilers, swine, beef, and dairy in the United States in 1997. Several of these companies are subsidiaries of other companies, and some are U.S. affiliates of European or Asian firms. Some of these companies represent mergers with earlier breeding companies and the original trademark names of these breeds may be still used for brand recognition.

In poultry, the breeding industry has developed into two distinct subectors, one for broilers and one for layers. There are fewer than twenty companies worldwide with breeding programs in either subsector (Rose, 1997). These breeding firms dominate the research, development, and production of new poultry breeds. Together, they maintain about forty to fifty types of pure lines (foundation stock) in inventory to have adequate genetic variability with different economic traits, even though they may market only six to eight different lines at any time. In the United States, seven companies conduct most of the breeding for broilers and two companies dominate the layer breeding industry. These companies also have franchises located in many countries where they sell their products and provide technical assistance to farmers.

The major players in the U.S. broiler breeding industry are Avian Farms, Arbor Acres, Cobb-Vantress, Hubbard (ISA), Peterson, Perdue, and Ross. All of Perdue's breeding stock is used in-house within the vertically integrated firm. Two of the companies, Cobb-Vantress and Avian Farms, are owned by vertically integrated poultry meat companies (Tyson Foods and Charoen Pokphand, respectively) but are operated independently and also sell stock to other producers (Henry & Rothwell, 1995). Peterson Farms develops stock for its integrated broiler parent firm, Crystal Lake, but most of Peterson Farms breeding stock is sold externally. It is estimated that the top four firms supplying broiler breeding stock have 77 percent share of the U.S. market. The other companies all serve international markets and sell their breeds either as fertilized eggs, chicks, parent, or grandparent lines. Although transferring grandparent lines to other affiliated companies reduces the company's control over its intellectual property, in some cases breeding companies have found this necessary in order to sell in foreign markets. Some countries have restricted the importation of poultry breeds to grandparent lines in order to foster the development of a local breeding industry (Narrod, 1997).

Only two firms supply 85 to 90 percent of the U.S. market for layer breeds. Hy-Line, originally part of Pioneer Hi-bred, has an estimated 70 percent share of the U.S. market. Hy-Line has a unique program of field testing its genetic stock in various locations around the world. The field tests take place in commercial flocks using Hy-Line parent stock. The firm then uses the field data to evaluate the performance of its genetic stock under commercial production conditions. DeKalb, which holds the second largest share of the U.S. market (15 to 20 percent), has its largest markets outside the U.S., including a large share of the Japanese market. In 1995, DeKalb sold its poultry subsidiary to Central Farm of America, an affiliate of Toshoku, Ltd., a Tokyo based trading company specializing in food and food products. Some consolidation has also occurred recently in the layer industry when Hubbard ISA acquired Shaver and Babcock. Hubbard ISA's major strength in the layer industry is in France, while its major U.S. focus is in broilers.

The swine breeding industry in the U.S. has a dualistic structure. One component consists of swine breeding companies that specialize in providing hybrid boars and gilts to farms. These companies, formed in the 1960s and 1970s, are similar to the poultry breeding companies in that they are large, international corporations (Johnson & Ruttan, 1997). These companies have developed superior pure line breeds for use in crossbreeding combinations that exploit heterosis for improved yield and quality. These companies provide both male and female (crossbred) parent lines to hog farms for terminal crossbreeding in which all offspring are marketed. Large hog producers tend to use this method, especially when they are part of integrated production systems. The second component of the swine breeding industry is composed of small breeders who provide purebred boars and serve local or regional markets. Purebred breeders mainly sell boars to farmers, who then select their own crossbred gilts for their breeding herd. This type of breeding is known as rotational crossbreeding, and is more commonly used by small and medium-size farms.

Historically, the small, purebred breeders supplied most of the swine genetic stock to farmers. In the past several decades the international swine breeding companies have gradually increased their market share. By 1989, the swine breeding companies sold 28 percent of commercial boars and 14 percent of gilts bought by farmers in the U.S., and their market share has probably increased since then (Johnson & Ruttan, 1997). The companies with the largest market share in the U.S. in 1996 were Pig Improvement Company (PIC), DeKalb Swine Breeders, Newsham Hybrids, Cotswold, Seghers, Babcock Swine, Farmers Hybrid, Genetic Improvement Service, Genetic Porc, and Danbred USA. DeKalb recently purchased the National Pig Development Company (NPD) and JSR. It is estimated from our survey that the top three firms supplying broiler breeding stock have an estimated 50 percent share of the U.S. market.

Breeders of dairy and beef cattle concentrate on improving pure line bulls for breeding with cows selected from farmers' herds. For beef cattle, farmers usually crossbreed their cows in order to increase yield through heterosis, while in dairy, farmers select superior cows from within the same breed (Holstein is by far the dominant dairy breed in the U.S.). Farmers obtain certain breeds from breed associations and specialized breeding companies that sell bulls to individual producers or provide insemination services. Artificial insemination (AI) is increasingly the reproductive technology of choice in the dairy and beef cattle industry. The number of companies providing AI for dairy and beef cattle declined from about 200 in 1950 to approximately 20 in the 1980s. The top six suppliers of AI are ABS Global, Accelerated Genetics, Alta Genetics, Cooperative Resources International, Select Sires, and Sire Power. Together, these companies have about 80 percent of the market share for insemination services for dairy and beef in the U.S. (C. Sattler, personal communication, 1998). Several of these companies also sell AI internationally. With the greater ease in transporting frozen semen and steady market expansion, AI prices have been decreasing (Funk, 1996).

2.4.4. Predictions of private research intensity. The factors that affect the profitability of animal breeding described above suggest that incentives for private investment in breeding differ across livestock commodities. These differences are summarized in Table 3.[1] If market size were all that mattered, we would expect research intensity (defined as the number of dollars spent on research per $100 of commodity production) to be about the same for each commodity. But different rates of growth in market size, and differences in technology opportunities, the costs of research, and the ability to appropriate the gains from research imply that research intensity will be higher for some commodities than for others.

Most of the factors described in Table 3 favor poultry, broilers in particular. Consumer demand for chicken meat has grown more rapidly than demand for other animal products in the U.S. and worldwide. Furthermore, genetic improvements in poultry can be more easily protected through hybridization. Finally, the concentrated market structure of the poultry breeding industry and the high degree of vertical integration in the broiler and layer industries enable private breeders to capture a greater share of the economic gains from research investments.

Some of these factors also describe the swine breeding industry, but to a lesser extent. While hybrid breeding helps swine breeders to protect their research investments, there remains significantly more competition from small swine breeders who provide purebred boars. In addition, fecundity and gestation rates imply that swine breeding is a slower process than poultry breeding. The development and diffusion of artificial insemination in

[1]In Table 3 and in the rest of the article, we group the beef and dairy subsectors together. Private incentives for breeding either type of cattle are quite similar. Furthermore, in our survey, most developers of cattle genetic stock supplied AI to both beef and dairy producers and were unable to break down their research investments into each subsector.

Table 3. Incentives for Profit-Seeking Investment in Livestock Research

	Broilers	Layers	Swine	Beef and dairy
Factors affecting private profitability of breeding research				
Market size				
Final product demand U.S. (billion $)	12.4	4.1	10.9	54.7
Final product demand World (billion $)	50	40	110	290
Growth in demand U.S. (%)[1]	4.7	0.4	1.1	0.6
Growth in demand World (%)[1]	4.9	3.1	3.1	1.1
Breeder sales U.S. (million $)[2]	200	60	850	56
Breeder sales World (million $)[2]	780	146	6,700	n.a.
Growth in breeder sales in U.S.	rapid	slow	moderate	moderate
Technology opportunity				
Fecundity and gestation	rapid	rapid	moderate	slow
Public research intensity in 1996 ($ of research/$100 of U.S. production)	0.24	0.31	0.90	0.59
Appropriability				
Hybridization	yes	yes	yes	no
Market structure (% integration in U.S.)	99%	99%	20–25%	5–10%
Predicted ranking of private research intensity	1	2	3	4

[1]Average annual percent growth in production between 1970 and 1996.
[2]Sales by specialized breeding companies only (does not include sales by small or part-time breeders). Beef and dairy breeder stock sales include sales of artificial insemination only.
Sources: Value of final product sales from Author's Survey (1998) and FAOSTAT; value of breeder sales from authors' survey; public livestock research spending from USDA's Current Research Information System; percent of US market vertical integration from Martinez and Reed, 1996.

swine and cattle has increased the size of the market that can be reached for a given genetic improvement, however. The market share of AI may expand even further due to disease concerns, because the use of AI reduces the risk of disease transference.

Market factors for pork are somewhat less favorable compared with poultry meat but probably more favorable than beef. Technology opportunity is least favorable for cattle, due to low fecundity and long gestation. Regarding regulations and trade restrictions, no clear differences among the commodities are evident; all are similarly affected.

The greater support for dairy and beef research relative to output value may also reflect political economy and institutional aspects. Dairy and beef producers may have been able to garner more political support given their wider geographic representation compared with pork and poultry. Inertia in public research institutions and universities may also make them less sensitive to changes in market conditions (Huffman & Evenson, 1993).

Taking all of these factors together, the incentive structure in livestock breeding suggests that private research intensity should be highest for poultry, followed by layers, swine, and finally cattle. Within the poultry sector, private research intensity should favor broilers relative to layers. This is the principal hypothesis of this article, and is examined empirically in the next section.

3. PRIVATE INVESTMENT IN LIVESTOCK BREEDING: SURVEY RESULTS

During 1997–98, the authors conducted a telephone survey of private-sector breeding companies for broilers, layers, swine, beef, and dairy with operations in the U.S. (companies contacted are those listed in Table 2). All companies listed in Table 2 responded to ques-

Table 4. Private Research Investment in Livestock Genetic Improvement in 1996

	Broilers	Layers	Swine	Beef and dairy	Total
Private research investment (million $/year)					
Breeding research in the US	64	16.7	19.1	18.6	138.4
Breeding research worldwide	81	19.7	31.3	n.a.	n.a.
Private research intensity ($ of research/$100 final product sales					
U.S.	0.52	0.41	0.18	0.03	
Worldwide	0.13	0.05	0.03	n.a	

Source: Private breeding research from authors' survey. Value of livestock production from Economic Research Service and FAOSTAT.

tions. The survey coverage is fairly complete for broilers, layers, and dairy, but does not include small, pureline breeders of swine and beef cattle. For private cattle breeding, the list of companies interviewed only includes those supplying improved genetic stock through artificial insemination. AI is now widely used in the dairy industry but is not yet as extensively used by beef cattle growers (Johnson & Ruttan, 1997).

In the survey, companies were asked to estimate their annual expenditures for animal breeding research and to give the number of full-time-equivalent scientists (i.e., a "scientist-year," or SY) at the Ph.D. and M.S. level employed in the United States and worldwide. Companies were also asked to give a break-down of the number of SYs allocated to applied animal breeding (quantitative genetics) and to more basic breeding research in animal molecular biology. Finally, companies were asked for their annual sales of breeding stock and to provide an estimate of the total market demand for breeding stock in the U.S. and worldwide. Below, only aggregate results for the commodity subsectors are reported in order to preserve the confidential responses of individual companies.

The survey results show that in 1996 the private sector spent at least $118.4 million for livestock breeding research in the United States (Table 4). Global estimates are only available for broilers, layers, and swine, as the responses from the cattle breeding companies only cover research conducted in the U.S. For the U.S. market, research investment in broiler breeding was by far the largest, at $64 million. Layers, swine, and cattle breeding each accounted for about $16–20 million in private research investment.

The estimates of private research intensity conform to the predictions of the incentives structure described in the previous section. Broiler breeding had the highest research intensity, at about 51¢ per $100 of producer sales of broiler meat, followed by layers (40¢ of research per $100 of producer sales of eggs), swine (17.5¢), and cattle (3.3¢). Global research intensities for broilers, layers, and swine are smaller but follow the same pattern as the U.S. For each of these commodities, research spending in the U.S. accounted for more than half of worldwide private breeding research. Most of the rest of the private research identified in the survey was carried out in Europe or Japan.

4. PUBLIC AND PRIVATE ROLES IN LIVESTOCK GENETIC IMPROVEMENT

The classic economic criterion for determining the appropriate roles of the public and private sectors in the allocation of resources is based on the notion of public and private goods. Public goods are defined as those that are non-rival (one person's consumption or use of it does not diminish its availability to others) and non-excludable (once the good is made public, it is difficult or impossible to limit anyone's access to it). Private goods are those that do not meet at least one of these criterion. Public goods, while they may be socially valuable, are generally not profitable for the private sector to provide. Thus, the hand of government is often required to provide an adequate amount of a public good (Fuglie et al., 1996).

Information is one example of a public good, because it is so easy to duplicate and redistribute it fits the non-rival and non-excludable criterion. For this reason research, whose main product is information, is usually considered a public good. Thus the private sector is likely to underinvest in research and the active participation of government in supporting science and technology can improve economic well-being. But if the private sector can exercise some degree of monopoly power or control over new technology (i.e., make it excludable), then it may be able to appropriate some of the gains of research and thus find it profitable to invest in research. As was described previously, appropriability in livestock breeding research is influenced by the ability to protect technology through trade secrets (hybridization), patents, and trademarks, and through market concentration and vertical integration of production.

The analysis of incentives in the first section and the results of the survey indicate that the degree of "public good" in livestock genetic improvement differs across commodities. Public and private roles also differ by field of science, with more basic research containing a larger public good component than applied research and technology development, because the results of basic research are difficult to patent or market as products. In Table 5, we compare the public and private allocation of scientific resources for each livestock commodity and for two fields of science, applied breeding in quantitative genetics, and more basic breeding research in animal molecular biology. Research resources are measured in full-time equivalent scientist-years, or SYs.

The figures in Table 5 indicate a division of labor between the public and private sectors that conforms to these notions of public and private goods. The number of private breeders in broilers and layers exceeds those of the public sector, while in swine and cattle (where private incentives are weaker) the public sector contributes a larger share of total breeding effort. In broiler breeding, for example, there were 45.25 SYs in the private sector compared with only 13.4 SYs in the public sector. For beef and dairy cattle breeding, on the other hand, there were 36.5 private-sector SYs compared with 133.2 public-sector SYs. For all commodities, the public sector allocated more resources to more basic breeding research (molecular biology) than the private sector, where by far the most research was allocated to applied breeding (quantitative genetics). For all of the commodities combined, 101 out of 197 public-sector SYs were allocated to molecular biology (51 percent). In the private sector, only 22 out of 128 SYs were allocated to molecular biology (17 percent). The rest were allocated to applied breeding.

Even for commodities such as poultry where the private sector now dominates breeding and genetic improvement, public research universities retain an important role in educating and training scientific personnel employed by private breeding programs. But the number of animal science departments in the United States has been declining due to closures and consolidations. By 1992, only 4 Ph.D. programs remained in dairy and only 6 Ph.D. programs in poultry science (National Research Council, 1995, p. 49). This has raised concerns about possible shortages of trained labor for private research and the loss of publicly supported basic research in animal sciences. In an effort to generate support for animal science programs, public universities and private entities have sought to establish regional consor-

Table 5. Public and Private Scientist-Years Allocated to Livestock Breeding in 1996 in the United States

	Broilers	Layers	Swine	Beef and dairy	Total
Public breeding research					
Applied breeding (SY)	6.9	3.3	13.5	72.7	96.4
Molecular biology (SY)	6.5	5.0	29.1	60.5	101.1
Total SY	13.4	8.3	42.6	133.2	197.5
Private breeding research					
Number of breeding firms	7	3	10	6	26
Ph.D. (SY)	29.3	9.0	18.6	16.5	73.4
M.S. (SY)	16.0	4.0	14.3	20.0	54.3
Applied breeding (SY)	40.8	9.0	24.3	31.5	127.6
Molecular biology (SY)	4.5	4.0	8.6	5.0	22.1
Total SY	45.3	13.0	32.9	36.5	127.6

SY = scientist-years (full-time equivalents).

Source: Public breeding research from USDA's Current Research Information System; private breeding research from authors' survey.

tiums to coordinate research, teaching, and extension among universities in neighboring states and to win more support from private industry for university programs (Havenstein, 1998). This type of cooperative effort helps to reduce the spillover problem in research (where one group or region benefits, but does not help pay for, research conducted by another group or neighboring region). It also reduces research redundancies that may occur when universities and/or private companies undertake the same type of research.

The poultry sector has probably had the most experience with regional cooperation, and with mixed results. Some efforts have failed due to political and administrative problems, inadequate funding and support, insufficient numbers of students, and a lack of mechanisms to reward faculty for out-of-state teaching, research, and extension (Havenstein, 1998). One of the most successful programs is the Midwest Poultry Consortium, which was formed with the cooperation of 24 private companies and 13 universities. In 1993, the consortium raised approximately $1 million from the private sector to establish the Midwest Poultry Science Undergraduate Center at the University of Wisconsin (Havenstein, 1998). Private sector members also use the consortium to channel money to universities for poultry research and to seek out potential employees through the consortium internship program.

5. SUMMARY AND CONCLUSIONS

The private sector is an increasingly important player in the research system that develops new technology for animal production in the United States. Private incentives for animal research are strongest where markets for improved technology are large, technical advances can be made relatively easily and quickly, and where intellectual property can be protected. Private research tends to concentrate on technologies that are likely to result in market applications in the near future.

Several multinational companies have emerged over the past several years to become major developers and suppliers of improved animal breeds for producers. In the U.S., while total private-sector animal breeding expenditures are less than public-sector breeding expenditures, the private sector is the major investor in poultry breeding and is responsible for most of the applied breeding research for broilers, layers, and swine. The public sector remains the major supplier of basic breeding research for all livestock commodities except poultry. The willingness of the private sector to make investments in basic poultry research may be due to high degree of market concentration and vertical integration in this industry. For large animals (dairy and beef), the public sector predominates in both basic and applied breeding research. Long gestation, low fecundity, and an inability to produce high-performing hybrid animals limit private research incentives for the large animal commodities.

In public animal research there has been a trend to reallocate some agricultural research resources toward more basic animal sciences. Public resources spent on basic animal science research complements private-sector capacity in applied animal research. Recently, public-private consortiums have emerged as a means to strengthen coordination and support for university research and education programs in animal sciences.

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